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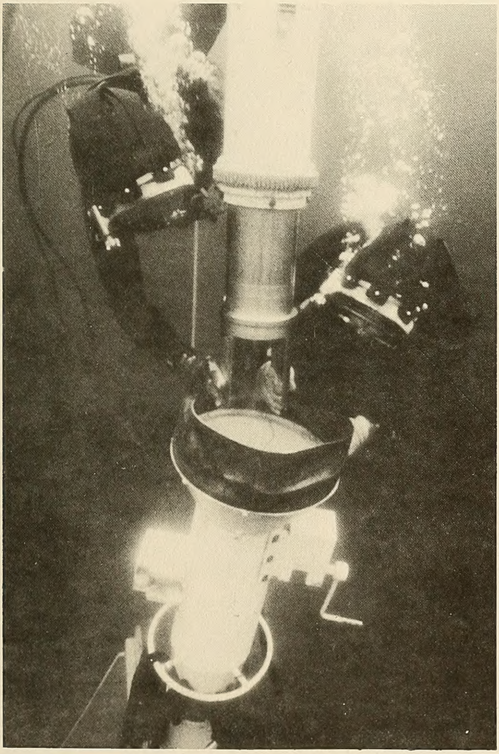

HIGH-POWER ELECTROMECHANICAL CABLE CONNECTORS FOR DEEP OCEAN APPLICATIONS

By

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In support of Navy underwater construction requirements, the Naval Civil Engineering Laboratory has developed prototype high-power electromechanical connectors for use with deep-ocean cable systems and structures. There are two basic connector configurations: one for mating underwater (wet) and one for mating in air (dry). Both are designed for 360 kw, 60 Hertz, 4,160/2,400 VAC power at depths to 6,000 feet, with a mechanical breaking

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20. strength of 50,000 pounds. The wet connector is capable of repeated underwater mating by divers, remotely operated actuators, or submersibles with manipulators. Increased performance in depth, strength, or power would require a simple extension of the design, although any significant increase in transmission voltage levels would require further development. These connectors were evaluated in a series of pressure-vessel and open-sea tests to depths of 6,000 feet. The final configuration performed with no electrical or mechanical degradation after 33 matings at depth. Sustained immersion and power tests for one year at 600 feet and in the tidal zone confirmed the endurance of the designs. This development is the first demonstration of a capability for underwater mating of major electrical/mechanical components of sea-floor structures.

CONTENTS

INTRODUCTION

This program supports the Navy's requirement for the development and operation of seafloor installations. It is part of the Deep Ocean Technology Program and was sponsored by the Naval Facilities Engineering Command. Electrical energy for these installations, at power levels from a few kilowatts to several hundred kilowatts, can best be provided from shore-based or surface-tendered sources [1]. Typical undersea installations utilizing such power supplies are illustrated in Figures 1 and 2. They include such components as bottom-laid cable, buoy systems, fixed seafloor structures, underwater work vehicles, diving stations, and tensioned arrays for scientific observations. As the complexity of these structures increases, the techniques of modular construction become more important and the ability to isolate or replace sections without recovering an entire structure becomes essential. The flexibility afforded by appropriately located connections for both installation and maintenance is a prime factor in obtaining efficient operation, optimum construction methods, and long life with minimum downtime.

A serious limitation in undersea operations prior to the developments reported here was that undersea cable connectors were not available for this range of power and strength applications. This lack of suitable connectors severely complicated structure and equipment installation and made maintenance both costly and difficult.

The development effort described in this report concentrated on high-power, high-strength connectors and was coordinated with related low-power connector programs at NAVSHIPS [2].

The specific goal was the development of a high-power electromechanical connector system capable of being mated either underwater (wet) or in air (dry). The desired performance of the cable-connector system was as follows:

1. 360 kw, 60 Hertz, three-phase, AC electric power, at 4,160/2,400 volts, 50 amperes per phase.

2. Breaking strength of 50,000 pounds with a working load of 14,000 pounds.

3. Operation over the entire depth range from 0 to 6,000 feet in the open ocean.

4. Repeated wet-mating capability by divers, or remote operation from submersibles.

5. Design life of 5 years or 500 operational matings.

The initial effort involved a review of existing technology related to undersea connectors to establish current problems and possible design approaches. A conceptual design was formulated for each of two approaches, air and underwater (dry and wet) make/break. Following laboratory tests of components, an experimental model of each configuration was fabricated. A series of pressure-vessel and sea tests was followed by development of second-generation (prototype) connectors.

CONCEPT FORMULATION

In December 1968 a contract was awarded to Southwest Research Institute (SWRI), San Antonio, Texas, for design, fabrication and laboratory tests of an experimental high-power electrical connector system [3]. Conceptual designs were required for a cable, a dry connector, and a wet connector. Both the wet and the dry connectors were to include pressure resistant penetrator pins in their internal construction so that the connectors might be adapted to serve as hull penetrators.

Cable Concept

The concept initially selected for the cable included four quad-configured No. 6 conductors which were insulated, shielded, and cabled around jute filler. Around the polyethylene inner jacket were 48 round steel armor wires, and there was a

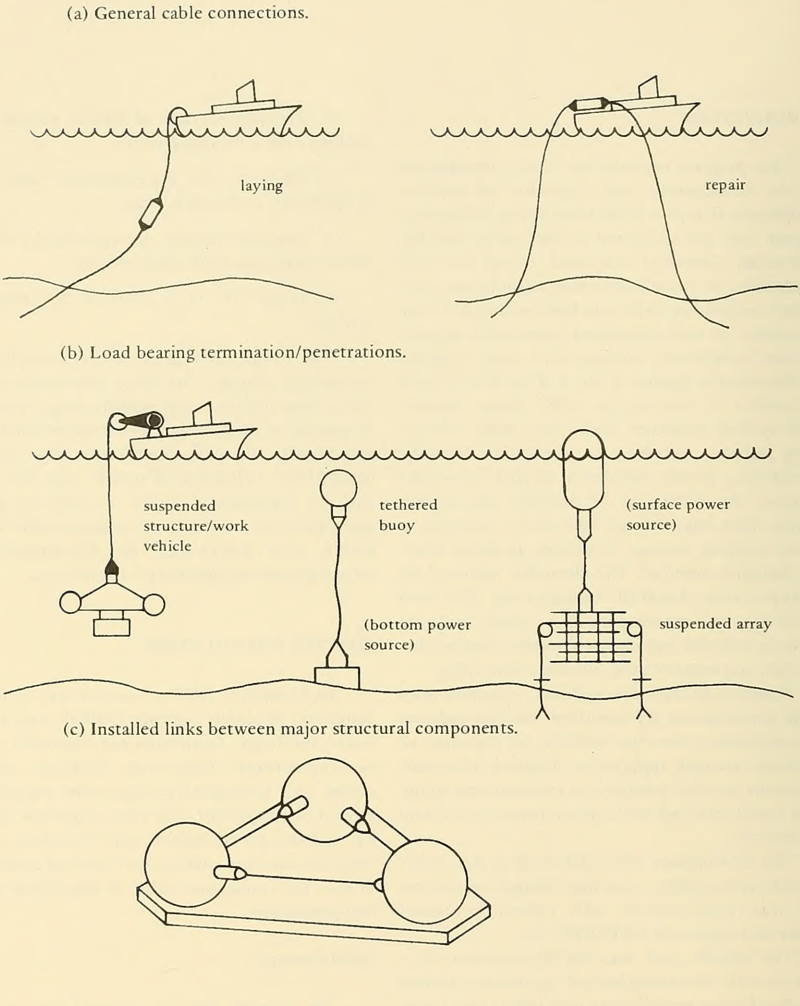


Figure 1. Undersea installations utilizing dry/wet connectors.

polyethylene outer jacket to protect the armor from abrasion and corrosion.

The cable as delivered was different from the initial concept because of procurement problems. The conductor configuration was a triad with three separate neutral conductors for better structural and electrical balance. The cable armor was stranded wires rather than solid. The inner jacket was polyurethane (0.050 inch) and the outer polyethylene jacket was 0.160 inch thick. The cable was not waterblocked, had no shielding, and had no bedding for the armor. As delivered, it weighed 2.14 lb/ft in air (1.07 lb/ft in water) and was very stiff. Although the basic configuration of the delivered cable was satisfactory, the absence of the many refinements in shielding, waterblocking, jacket thickness and armor configuration resulted in only marginal cable performance during later system tests.

Dry Connector Concept

The dry connector concept (Figure 3) involved a stainless steel cylindrical body with one internal main bulkhead near each mating end. Fused-glass penetrator pins through this bulkhead extended back into the body toward the cable termination area and forward into an oil-filled, pressure-compensated chamber which was formed when the two connector halves were mated. The pins in the oil-filled chamber mated with an interference fit. The pins were solder-spliced to their respective phase leads, shielded with stainless steel sleeves, and completely potted in polyurethane. This potting included the entire interior of the connector body. The cable armor was terminated by flaring it and clamping it between two flat compression rings.

Wet Connector Concept

The wet connector concept (Figure 4) utilized the same urethane-potted cable termination and penetrator pin techniques as the dry connector. The design differences were primarily in the area of the mating ends of the penetrator pins.

The male half was fairly simple and had no moving parts. The penetrator pins simply extended out from the face of the connector about four inches with a ring contact about halfway back along their length.

The female half was much more complex. Each of the penetrator pins had an offset sleeve contact on the mating end and was completely potted in polyurethane, except for a hole from the front of the connector through the urethane to the sleeve contact. This hole was filled with a sliding dummy piston made of glass-filled Teflon. This piston was double O-ring sealed near the outer end and the piston was spring loaded and pressure compensated via a small oil-filled chamber behind it. The piston was to exclude seawater from the interior when the connectors were unmated.

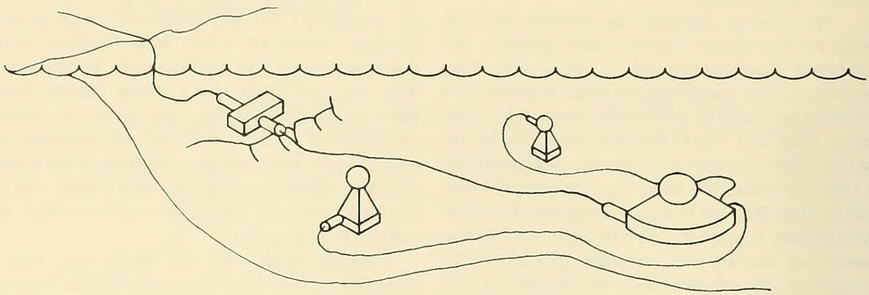
During mating the two halves were held in alignment by two large projecting surfaces from the male half which acted as a guide cradle. The two halves were pulled together by a large single-throw lever linkage and as the male pins entered the female cavities they displaced the dummy pistons. The O-rings were intended to wipe the seawater from the male pins.

Fabrication and Delivery

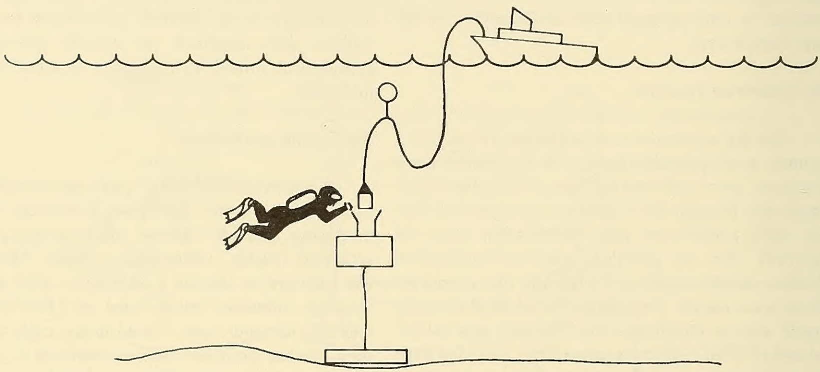
Considerable difficulty was experienced in the manufacture of the fused-glass penetrator pins, in producing void-free massive urethane pots, and in achieving reliable compensator designs. The design was amended to include a cable strain relief after the first dry connector tested failed at 2,300 feet from seawater intrusion near a bend in the cable termination. Further problems were encountered in attempts to disassemble the urethane-potted cable termination and pin splices. As the main body was being unscrewed from the base the urethane transferred enough stress to the penetrator pins to shear off three of the four pins. The remaining urethane required three weeks to dissolve. There is no way to easily disassemble a large urethane pot of this type without seriously damaging the rest of the connector components. This poor reparability proved to be a constant source of aggravation during the test program.

Six sets of hardware were fabricated (three dry and three wet). Two sets were supplied with short sections of cable attached (20 to 60 feet) and the remaining sets were used to assemble two 600-foot cable sections for use in loop power tests.

(a) Shore supply to bottom structures (for both installation and maintenance).



(b) Surface supply to bottom structures (intermittent or continuous).



(c) Component assembly underwater/add-on features.

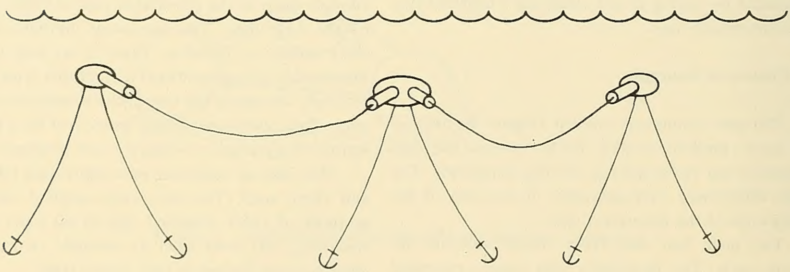


Figure 2. Undersea installations utilizing wet connectors.

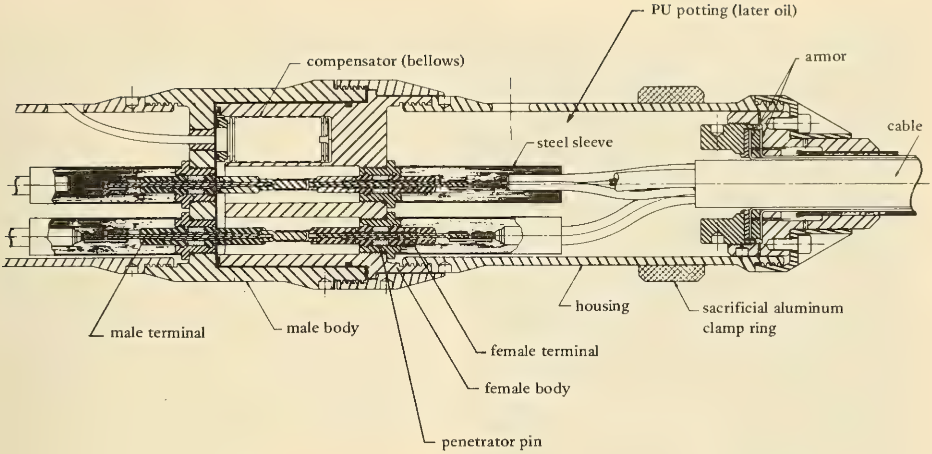


Figure 3. Experimental dry connector schematic.

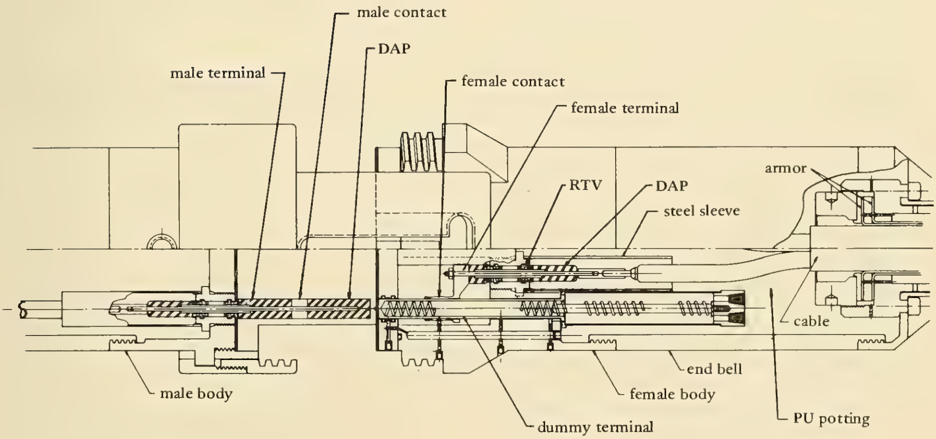


Figure 4. Experimental wet connector schematic.

TESTS OF EXPERIMENTAL CONNECTORS

Because the dry-connector concept was mechanically much simpler than the wet, the initial tests of the dry connector moved directly to sea trials, while the wet connector mating functions were being more closely studied under laboratory conditions.

Experimental Dry Connector

The details of the NCEL* test and evaluation of the experimental hardware were reported in Reference 4 and are briefly reviewed here. A cross section of the experimental model is shown in Figure 3.

In preparation for the NCEL SEACON-I experiment [5] the experimental dry connectors were tested at sea three times. In the first test the dry connector failed (shorted) at 2,300 feet. In the next two tests at 600 feet the dry connector performed successfully. One dry connector was then installed on the SEACON [5] structure and emplaced with the structure at a depth of 600 feet in the Santa Barbara Channel for one year. During this test the connector was used to power the structure at full voltage every two to three months, and, upon recovery, the connector showed no sign of electrical or mechanical deterioration.

After repairing the damage from the 2,300-foot test and modifying the strain reliefs, the dry connector was again taken to sea. During this test the connector failed (low insulation resistance readings) at 4,500 feet. Inspection revealed that the connector seals had failed and the interior was flooded with seawater. Review of the connector construction revealed that the compensator volume was too small so that the compensator would fail to function at between 2,000 and 3,000 feet even if filling was perfect and there was no trapped air in the system. Tests with an auxilliary compensator in the pressure vessel showed that the oil contamination problem was correctable, but the cable termination area (potted in polyurethane) still leaked and shorted out. This was attributed to the fact that urethane experiences a compressive set under pressure and does not instantaneously return to shape as pressure is released. This causes water to be literally pumped in around the conductors and penetrator pins as pressure is cycled.

A set of dry connectors was also assembled and left under full voltage at shallow depth in the tidal zone of Port Hueneme harbor for five months. This test was completely successful and showed that long-term immersion and power had no degrading effect on the connector performance.

A mechanical test of the cable termination was performed by attempting to lift a 21,000-pound concrete block. The connector lifted the block for about one second and then pulled completely free of the cable. The termination, which had been designed for a 50,000-pound breaking strength, failed completely.

In summary, the experimental dry connectors had the following major deficiencies:

1. The polyurethane potting compound provided no effective waterblock for the cable termination/conductor breakout area and penetrator pin splices.

2. The cable termination design utilizing compression rings on the flared armor was inadequate. (It would also be very difficult to install in the field.)

3. The compensator design was both too small and unnecessarily complicated (positive overpressure was not required).

Experimental Wet Connector

The wet connector and the dry connector have many components in common. The cable strength termination, the conductor waterblock, the penetrator pins and splices, and the basic electrical contacts are nearly identical in both designs (see Figure 4). Therefore, the results of the dry connector tests on termination strength, contact performance and related items were applicable to the appropriate sections of the wet connector; the wet connector test program essentially began where the dry connector tests left off. In addition to the mechanical and electrical performance requirements which must be met by the dry connector, the wet connector has a unique set of problems related to the process of

* On 1 January 1974 redesignated the Civil Engineering Laboratory (CEL) of the Naval Construction Battalion Center, Port Hueneme, California 93043

accomplishing the actual mating operation. This process consists of two basic and nearly independent steps:

1. Rendezvous and alignment. This step involves all the maneuvers required to get one half of the connector into the immediate vicinity of the other half, such as picking up one end of a cable and towing it to a structure to which it is to be mated. This step also includes rotating and translating the connector so that the longitudinal axes of the connectors coincide and the phase pins are correctly matched.

2. Mating. This is the actual mechanical connection of the two halves and the completion of electrical contact, with the attendant contact and insulator wiping action. In the concept used here, the mechanical and electrical operations are accomplished simultaneously, utilizing a linear motion of about 3 inches.

The interface between these two steps is the guide mechanism (Figure 5) utilized both to control the connector during the last few inches of alignment and to effect the actual mating operation. The power and control functions for both operations are provided by either divers, a remotely operated actuator of some sort, or a submersible with manipulator arm.

The test program was designed to first investigate the mating operation under laboratory conditions, then attempt the operation under very simplified rendezvous conditions, and then complete a more complicated rendezvous and mating in the open ocean on an operational structure.

Mating Tests. Initial attempts to quantify the performance of the experimental hardware were made in a shallow tank of seawater at one atmosphere pressure (just below the surface). In general, the phase-to-ground resistance of the connectors degraded with repeated mating. Examination of the oil in the female connector indicated that seawater did intrude and that dirt and O-ring particles were also present. Inspection of the O-rings revealed that they had small spots sliced or pinched off them, as opposed to being abraded from friction. Both the O-ring damage and the water leakage were due primarily to the fact that the square edges of the male pins were easily chipped in trying to start them into the female connector. The roughened edges produced small cavities to pass seawater under the O-rings and possibly to damage them. This is a problem in any pin-wiping system and can be improved by using tougher pin materials, better alignment techniques and more rugged seals.

Figure 5. Wet connectors being mated by divers.

From these tests it became apparent that although the wet connector system did work at the shallow depths it did so only marginally and that there were many obvious areas requiring considerably improved design if reliability was to be achieved. The next steps were to investigate the effects of increased depth and to begin studying adaptability of the connectors to handling by divers.

Shallow tests by divers with the connectors on a submerged bench indicated that the connectors—when divorced from the forces of attached long cables—could be mated with ease. For open-ocean operations, however, there were two major modifications which had to be made before divers or a submersible could even begin to align and mate the connectors:

1. The connectors had to be isolated from the forces and attendant motion transmitted through the heavy attached cables, particularly cables to ships at the surface.

2. The connector halves themselves must either be made neutrally buoyant or be affixed to a structure.

Rendezvous and Alignment Tests. The initial sea tests were made in a vertical mode, with the female half attached to a test stand. As shown in Figure 5, a guide cone was attached to the vertical female connector half and equipped with gears to align and then mate the male half to the female. A variable-buoyancy lift bag was used to provide a motion-isolating catenary in the cable from the surface and to make the male connector half nearly neutral in the water. The gear system enabled the divers to rotate the male connector and to crank the halves together while the cone held them in alignment.

The entire system was taken to sea and tested with the female held in a stand which rested on the bottom in 50 feet of water. The divers were able to achieve neutral buoyancy on the male cable and mate the connectors on the first try within 25 minutes of entering the water. The stand for the female was 20 degrees from vertical, 50 feet away from the boat. The male connector had to be rotated a full 180 degrees by the gears to obtain correct phase-to-phase orientation.

The entire system was later taken to the SEACON site for further test and demonstration. The guide cone was attached to the female connector at the SEACON Station S buoy at 50 feet and the male connector was successfully mated underwater by divers, this time in a strong current (0.75 to 1.0 kt). The system functioned electrically, and the SEACON structure was powered through the just-mated wet connector and the dry connector attached to the SEACON structure at 600 feet. The handling techniques for this operation were very successful.

To summarize, the experimental wet connector had the following major deficiencies:

1. The pin-wiping technique used to dry the contacts during mating was unreliable and degraded with only one to three matings.

2. The pressure-compensating system and cable termination had the same inadequacies as the dry connector.

In addition to the major discrepancies listed above, the experimental program revealed a host of minor areas for improvement in both the wet and the dry connectors. Most of these had to do with material selection or design details. A summary of these various problems follows:

1. Materials.

a. The use of 316 stainless steel for the connector housings was acceptable in these relatively short-term tests, but for immersions of several years the known crevice-corrosion properties of stainless steel would make titanium or 90-10 copper-nickel a better choice. In applications requiring minimal mechanical strength the housing even could be made of a plastic.

b. The use of glass-filled Teflon in the dummy pistons of the wet female half was unsatisfactory because of the poor structural properties of the material. Under pressure the rods deformed and stuck in the cylinders, and they scratched easily. DuPont Delrin (a nonpolar plastic) proved superior.

c. The use of diallyl phthalate (DAP), RTV silicone rubber and glass in the penetrator pins was also unsatisfactory. The differing bulk moduli, dielectric constants and dielectric strengths led to tracking along the various interfaces after the very weak bonds along them had been sheared because of differential expansion and contraction under pressure. At high pressure the RTV did not seal the face of the fused-glass pins on the wet side of the male connector. At high voltage there was substantial leakage current along the glass/RTV interface. Penetrator pins and other insulated sections should use the absolute minimum variety of materials.

2. Design Details.

a. The use of a single O-ring seal on the wet connector dummy pistons eventually proved successful, but only after considerable redesign of the faces of the pistons and matching male penetrator pins to eliminate misalignment and to ensure that the piston-pin combination presented an essentially smooth

cylinder to the O-ring seal as mating occurred. The early design had produced severe O-ring damage because of sharp, rough edges at the interface.

b. The bail linkage used for initial mating operations of the experimental wet connector was not adaptable to manipulator operation because manipulator arms cannot in general effect rotations about remote axes. The linkage also did not assist in the basic assembly and alignment of the connector halves.

c. Because the mating guides had to be adapted to the existing experimental connector models, the final assembly was very heavy and bulky. Even after prototype work there was still need for considerable refinement in the mechanical alignment system to provide smoother operation and easier handling.

d. The exposed male penetrator pins were very fragile and required protection during handling.

e. The face of the experimental wet female connector was not protected against fouling or siltation. Provisions for this protection must be included in designs for long-term immersion.

The wet connector mating, and powering of SEACON through the two connector types concluded the test phase of the work on the experimental wet and dry connectors. Effort was next directed to the development and test of the prototypes.

PROTOTYPE DEVELOPMENT

The prototype models represented a major redesign of the connectors and in fact were the result of a different design philosophy than that used on the experimental models. The electrical portions of the experimental models, including such items as the contacts and conductor arrangements, had performed quite well and were unaltered in the prototype design. Most of the problems had occurred in the sections of the connectors designed to prevent the intrusion of seawater. The NCEL prototype philosophy was to design the connectors to operate with some seawater intrusion and to use a simple, evenly balanced pressure compensation, rather than the more elaborate scheme utilizing positive internal pressurization, multiple seals and extensive urethane potting to totally preclude admission of seawater. The prototype design therefore had these major objectives:

1. Make the internal insulation as self-healing as possible. This implied the use of fluid dielectrics.

2. Make the entire system as completely pressure-balanced as possible. This also implied fluid dielectrics, with minimal internal fluid constrictions.

3. Provide tolerance of some seawater leakage. Under the guidelines of Reference 6 this implied a dielectric which was not miscible with seawater, and a design which provided physical separation of contaminating water from high-voltage leakage paths.

4. Build in reparability. This implied interchangeability of parts, mechanical assembly techniques (such as threads instead of welds) and minimal use of permanently potted components.

Prototype Dry Connector

Modifications. While the experimental long-term immersion test was still in progress, work was completed on a modified or prototype version of the dry connector (see Figure 6). The cable termination was changed to a large Dyna-Grip system from Preformed Line Products, which uses preformed helical rods wrapped around the cable as a gripper or "stopper." These rods are then compressed in a sleeve much as the armor wires would be in more conventional designs. A heat-shrink boot from the AMP Corporation was used to seal the conductor breakout into the interior of the connector. The conductors were then spliced to the salvaged penetrator pins by a solder splice wrapped in insulating tape and covered with a semiconducting heat-shrink tube from Raychem Corporation. The heat-shrink tube provided a linear voltage stress gradient along the surface of the insulation. The existing connector shell was used with the addition of an adapter ring to connect the cable termination to the shell. The joints were O-ring sealed, and the inside of the housing was filled with white mineral oil. A small external bladder was used to pressure-compensate the system.

Tests and Results. The prototype connector half was mated with the female half (original design)

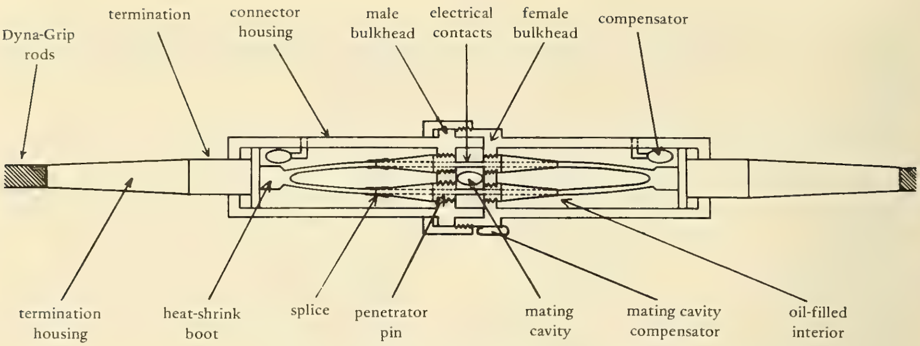


Figure 6. Prototype dry connector schematic.

which had been recently recovered from the long-term immersion test. The assembly was placed in the NCEL 72-inch pressure vessel and pressurized at 100 psi per minute to 3,000 psi (6,750 feet), held for one hour, depressurized, and recycled at the same rate to 500 psi for 15 minutes. There was no electrical degradation of either connector half during the test. Because of the difficulty of adapting seals to the existing housing seams, the prototype housing leaked and the compensating mineral oil was found to contain 15% seawater upon disassembly. Since there was no electrical degradation, the test confirmed the effectiveness of the heat-shrink seals around the individual conductors and splices; the design is genuinely redundant and will tolerate at least partial contamination.

The strength of the cable termination (Dyna-Grip) was tested by mating one prototype half with one experimental half of a dry connector and attempting to lift a 21,000-pound concrete clump as described in the discussion of the experimental test program. Although the experimental termination failed, the Dyna-Grip showed no ill effects at all. Further testing for fatigue, corrosion and other effects will have to await employment in larger-scale systems at sea.

The entire dry connector prototype in its present form can be assembled and attached to a cable end by two men in about six to eight hours. This is a major improvement over the one-to-two days required to install even small connectors utilizing potting techniques. The NCEL prototype design also requires no special tools or controlled conditions for installation.

The contacts and penetrator pins are the same as those in the experimental model (fused glass) which showed no degradation after five months of shallow-submerged continuous operation and one year of submerged (600 feet) intermittent operation. Glass-filled epoxy pins developed later for use in the wet connector should be used for applications requiring less stringent open-face pressures (such as for in-line operation rather than as a structural penetration).

Evaluation. The NCEL high-power electromechanical connector (dry) is now ready for final design to fit whatever specific applications may arise. With the exception of the penetrator pins and cable termination, production of the entire dry connector is well within the capacity of any user with access to a machine shop. Costs may be expected to vary considerably with the desired mechanical strength because of the termination, housing and resultant machining effort. The cost would also increase if fused-glass pins were used. The connector depth rating is exclusively a function of the compensator volume, and the life is principally a function of the choice of housing materials. Performance has been demonstrated to a simulated depth of 6,750 feet and over a sustained immersion of one year at 600 feet.

Prototype Wet Connector

Modifications. A set of experimental wet connectors was disassembled for analysis of failed internal components and for modification as

prototype connectors. The greatest problem encountered in the disassembly was the effort involved in dissolving the polyurethane potting material. After nearly four weeks of dissolving the polyurethane, the internal components were available for inspection.

It was later discovered that the polyurethane potting can be quickly removed by first baking the assembly at 400-500^{O}F for 3 hours. The polyurethane is thermally decomposed to an easily crushed solid that is readily removed. However, this process damages all components that are not metallic.

Analysis of the internal components of the experimental connectors presented the following results:

1. Dummy Piston. As shown in Figure 7, the dummy pistons were severely deformed due to cold flow of the glass-filled Teflon material from which they were machined. This deformation accounted for the stiffness of operation of the pistons in the assembled connector. It is believed that this deformation was caused by compression or shrinkage of the surrounding polyurethane material.

2. Penetration Pins. Figure 8 shows tracking paths between the high-voltage cable terminal and the threaded fitting that is at ground potential. This is positive evidence that the polyurethane did not always seal to the DAP and other materials that make up these penetrators.

3. Pressure-Equalizing Pistons (Compensators). The four pressure-equalizing pistons were displaced by springs that were located on the seawater side of the piston. These springs were severely corroded, and corrosion products contaminated the seawater in the compensator cylinder. The corrosion products and other foreign material that collected in the cylinder caused the pistons to jam.

It was also found that the female contact ring was located too close to the side of the urethane-filled cavity. The spacing was less than 1/8 inch, which was a very marginal thickness for the dielectric strength of urethane. The problem was compounded by the fact that an oil flushing duct was drilled through the housing and urethane directly into the contact area. This provided a trap for contamination and a very short tracking path for high voltage leakage currents. Previous high voltage pulse tests of the assembled connector had indicated that breakdown did in fact occur at this point.

To correct the deficiencies found during the testing and disassembly of the experimental connector, one wet connector set was extensively modified as a prototype. As shown in Figure 9 the modifications include new and more reliable electrical pins, pin-wiping seals, dummy pistons, pressure-equalizing system, electrical insulation, and a Dyna-Grip termination. The new design can now be quickly assembled or repaired at sea because no potting compound is used.

The modified male pin, female contact assembly, and dummy piston are shown in Figure 10. The male pin contact is gold-plated copper and is insulated with molded high-quality, glass-filled epoxy. The pin is 0.613 inch in diameter and has an overall penetration of 2.375 inches. The convex tip of the copper contact is machined to align with the dummy piston in the female half. The female contact assembly consists of a 0.375-inch copper rod, a crimp type wire terminal and a gold-plated copper female contact (taken from the experimental model), and is insulated with a machined sleeve of acetal material (DuPont Delrin). The female pin insulator is machined to provide proper contact alignment, a hexagonal portion for reliable assembly with a socket wrench and a cylindrical surface that is turned to the same diameter as the cable insulation to aid in taping and insulating the terminal. The dummy piston is a copy of that used in the experimental model except it is made of Delrin and has a concave surface that aligns and nests with the leading edge of the male pin.

Several types of pin-wiping seals were tested during these modifications. The pin-wiping seal shown in Figure 10 is a conventional, automotive-type lip-seal. Several similar seals were tested for pin-wiping performance using the test apparatus shown in Figure 11. The apparatus was submerged in seawater and a male pin was used to depress the dummy piston simulating an underwater connector mating. The mating sequence was repeated 50 or more times for each type of seal. Monitoring of the dielectric strength of the insulating oil was the indication of the relative performance of the seals. In general the single O-ring would reliably allow the

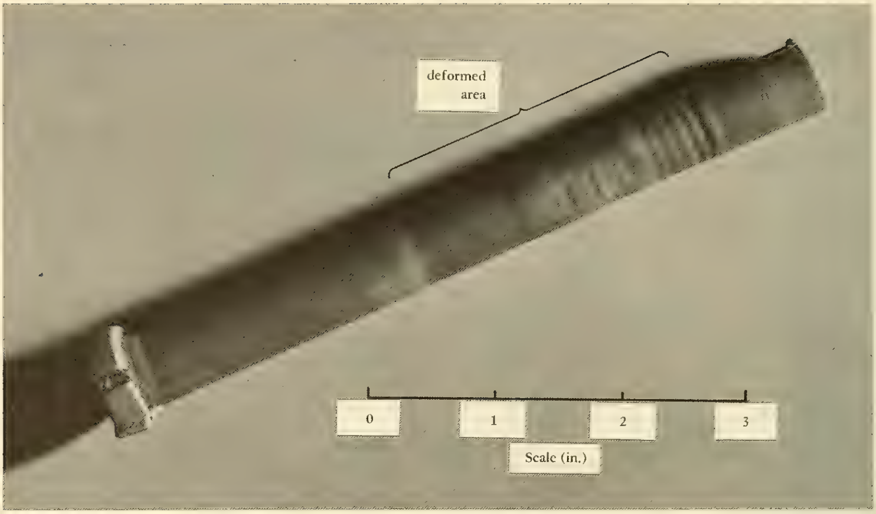


Figure 7. Distorted dummy piston removed from experimental connector.

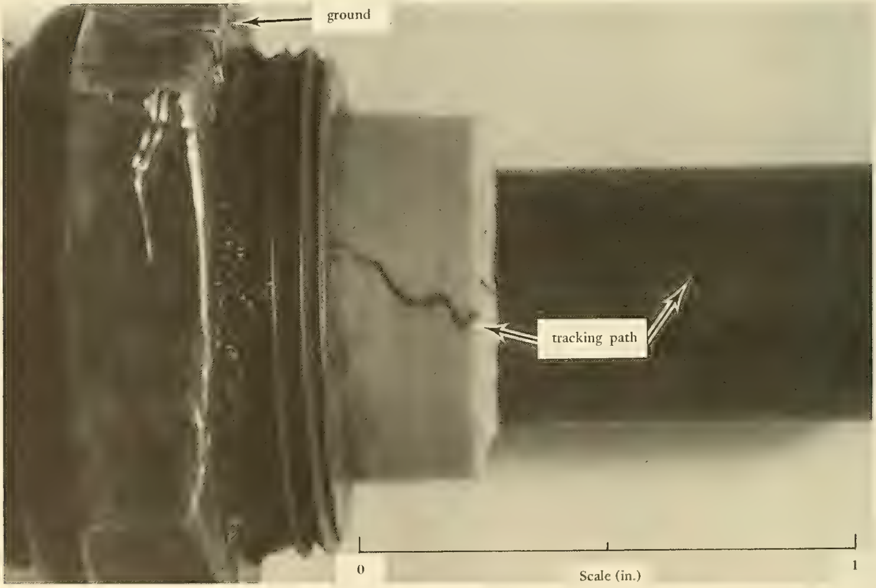


Figure 8. Penetrator pin removed from experimental connector showing electrical tracking path to ground potential.

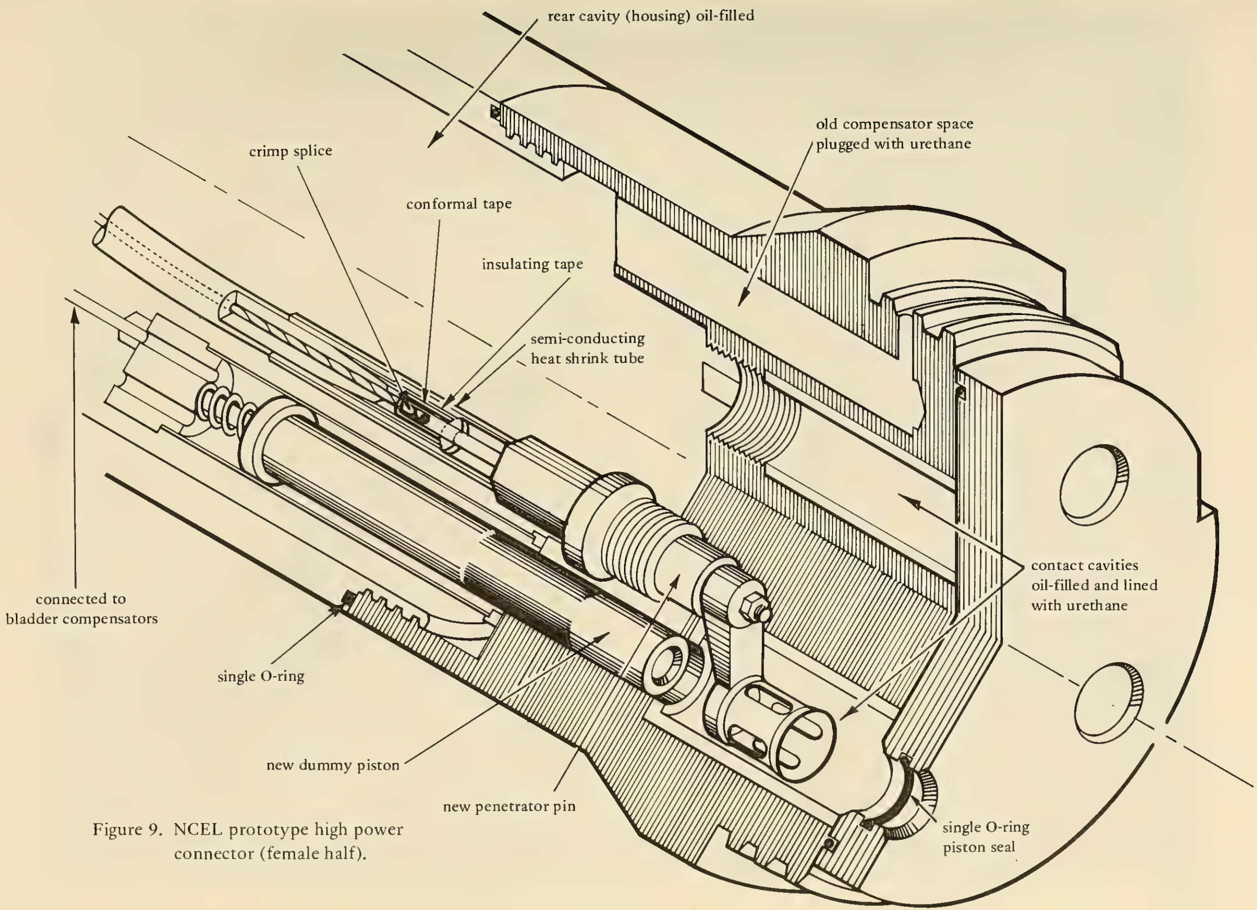


Figure 9. NCEL prototype high power connector (female half).

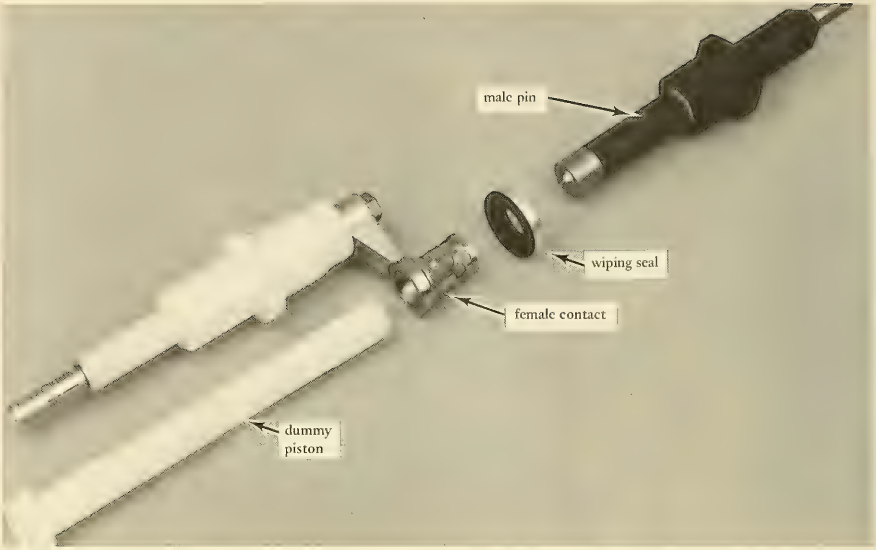


Figure 10. Modified male and female electrical contacts, dummy piston and seal for prototype connector.

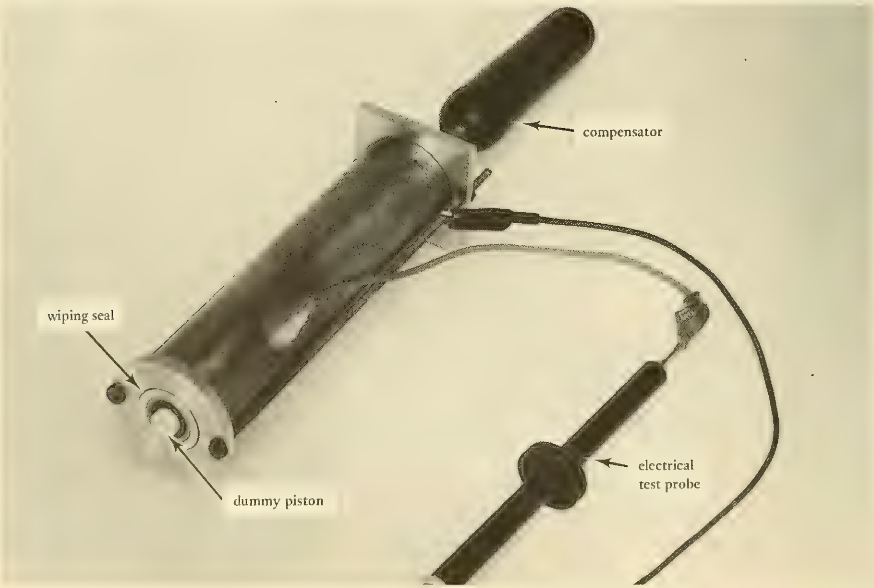


Figure 11. Pin-wiping seal test apparatus.

dummy piston to reseal the female connector and was most effective in wiping the male pin. For these reasons the O-ring seal was used in the final test program.

Figure 12 shows all of the components of the modified wet connectors. Figure 13 shows the male half nearly assembled. A heat-shrinkable boot is used to seal and waterblock the cable to the Dyna-Grip assembly. Two rubber pressure-equalizing bladders provide 2 pints of compensation volume. The stainless steel (Type 316) shell sections are threaded for assembly and sealed with O-rings. The bladders are installed and connected to the seawater vent. At high pressure, seawater inflates the bladders to compensate for volumetric shrinkage (or compression) of the internal fluids and cable materials.

The connector is filled with approximately one gallon of dielectric oil (white mineral oil, Type USP) at an initial pressure of 50 psig to test for leaks. The pressure is bled down to atmospheric, at which the trapped air and excess oil are displaced. The seawater vent is temporarily plugged during the bleed-down to keep the pressure-equalizing bladders fully deflated.

The female half of the connector, as viewed from the front end with the faceplate removed, is shown in Figure 14. The four female contacts are shown with the dummy pistons in place. The oval-shaped contact cavity is lined with about 0.250 inch of polyurethane insulation (PRC No. 1547). If moisture accumulates in the female connector this insulation will isolate the droplets from direct contact with the steel housing. This reduces the amount of leakage current between the contact and the connector body.

Figure 15 shows the female connector subassembly rotated with the cable terminals and dummy pistons visible. Four spring retainers and the pressure-equalizing bladders complete the assembly. Polyurethane was used to fill the four cavities originally provided for the pressure-equalizing cylinders.

Figure 16 shows the prototype female connector mostly assembled with the compensators, dummy pistons, spring-retaining faceplate, and Dyna-Grip cable termination in position. The rear body section is later installed and the connector is filled with dielectric oil, as is the male connector. The female connector is purged by holding the connector in a vertical position with the faceplate up, and depressing the dummy pistons to vent air and oil until clean oil is being passed. A small hand pump is temporarily connected to the connector fill port for this purpose.

Figure 17 shows the completed wet connector. The mated connector is approximately 3 feet long, 8 inches in diameter, and weighs 150 pounds in air and 100 pounds in water. The Dyna-Grips extend approximately 9 feet beyond the connectors.

Test Program. A comprehensive test program was outlined to determine the performance and reliability of the prototype wet connector. The principal new technologies which required testing are given in Table 1 with applicable parameters for the tests. This matrix was the basis for planning and conducting the following tests:

1. Initial high pressure test of seals, compensation system, and high-voltage insulation

2. Power transmission test in shallow water

3. Underwater mating test in shallow water

4. Underwater mating test in high-pressure vessel with high power transmission (120 kw)

5. Undersea mating test at 4,000 feet (remote mating fixture)

6. Remote mating test using deep submersible manipulator

Each of these tests is discussed below.

Initial High Pressure Test. The prototype connector was first tested in the NCEL Deep Ocean Laboratory (DOL) under cyclic pressure (5 cycles) to 4,500 psi at 40^{o}F. A hipot instrument monitored the insulation level of the individual phases at 6,000 VDC. The insulation level remained excellent throughout the test (greater than 10 $M\Omega$). After removing the connectors from the test chamber, the compensation oil was drained from the connectors and no salt water contamination was found. The results of these tests showed excellent performance of the seals, compensation system, and high voltage insulation.

Power Transmission Test. The current-carrying performance of the mated connector was tested initially by connecting all phases in series to a low-voltage high-current transformer. The current was

Figure 12. Components of the prototype wet connector.

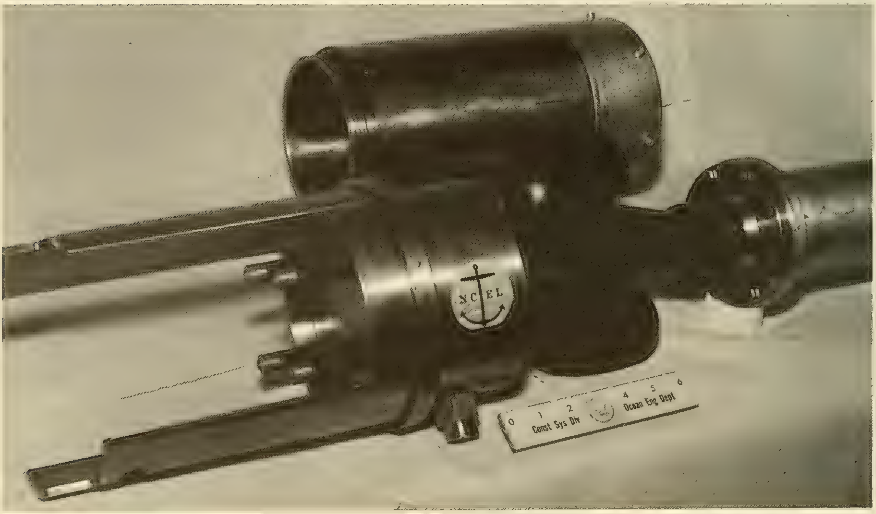


Figure 13. Prototype wet connector (male half).

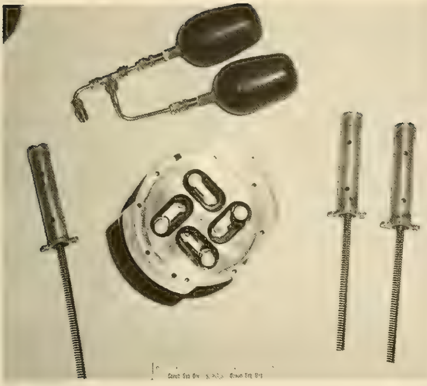


Figure 14. Female connector subassembly with faceplate removed.

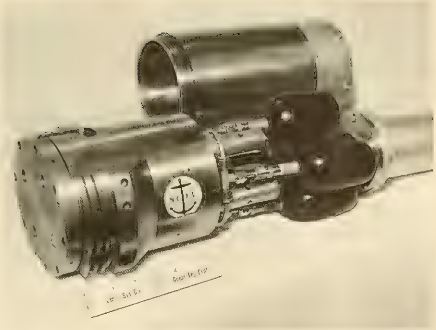


Figure 16. Assembly of female wet connector.

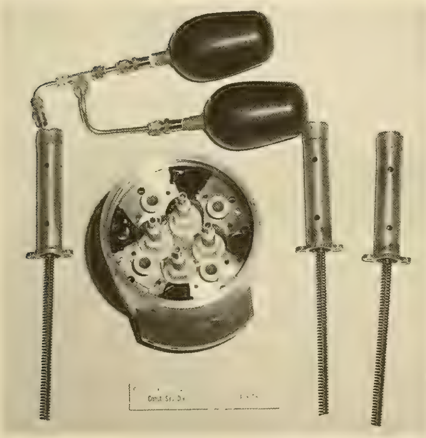


Figure 15. Female connector subassembly (rear view)

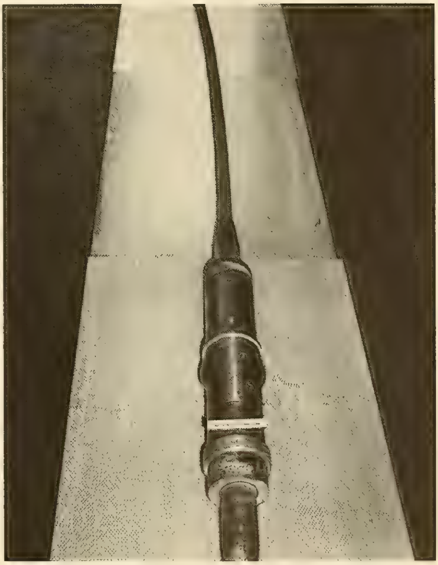


Figure 17. Completed prototype wet connector.

adjusted to 50 amperes and sustained for 7 hours. The voltage drop across the connector and cables increased from 2.9 to 3.0 VAC due to the temperature rise of the cables.

This test was followed by a power transmission test in a dry environment. Connections were made as shown in Figure 18. The connector transmitted 100 kw for about 3 hours at 4,160 VAC.

The connector was then installed in a 10-foot-deep tank of seawater for 2 weeks. Again 100 kw was transmitted for two 4-hour periods, one at the initiation of the test and one at the conclusion. Leakage currents remained less than 3 μA at 8,000 VDC during the 2-week immersion. The performance of the connectors was again excellent.

Underwater Mating Test. A battery-powered, remote-controlled drive system was fabricated to mate the connector in a series of experiments to determine the performance of the pin-wiping seals and the overall performance as a deep-ocean wet connector. The drive system was designed to activate the alignment and guide cone assembly used earlier during diver-supported mating tests. The first test was performed in about 10 feet of seawater, where the connector was mated five times. The drive system used with the connector was geared to about 10 rpm and the male connector moved about 3 inches in 90 seconds to complete a mating or unmating. The leakage current remained at or below 1 μA for each phase during thest tests.

The connector was moved to the NCEL 72-inch-diameter DOL for mating tests under high-pressure with power transmission. High voltage electrical cables and penetrators were used to provide power transmission through the pressure vessel head to the connector as shown in Figure 19. The pressure vessel was filled with cold seawater ($5^{o}C$) and pressurized to 3,000 psi. The connector was mated and unmated a total of 16 times and up to 120 kw of power was transmitted at intervals during the 5-day test. Insulation and current-carrying tests made at the conclusion of the experiments showed no degradation of electrical performance from the multiple underwater matings at high pressure.

Undersea Mating Test. The electric actuator was again used to evaluate the electrical performance of the connector during and following multiple underwater matings, this time under actual at-sea conditions. The arrangement for this test is shown in Figure 20. A high-strength electromechanical cable was used to lower the battery-powered, remote-controlled connector to a depth of 4,000 feet. A high voltage coaxial circuit within the E/M cable was used to monitor the insulation leakage current at 8,000 VDC during the test. Twelve matings were achieved during this test, and again there was no indication of electrical degradation.

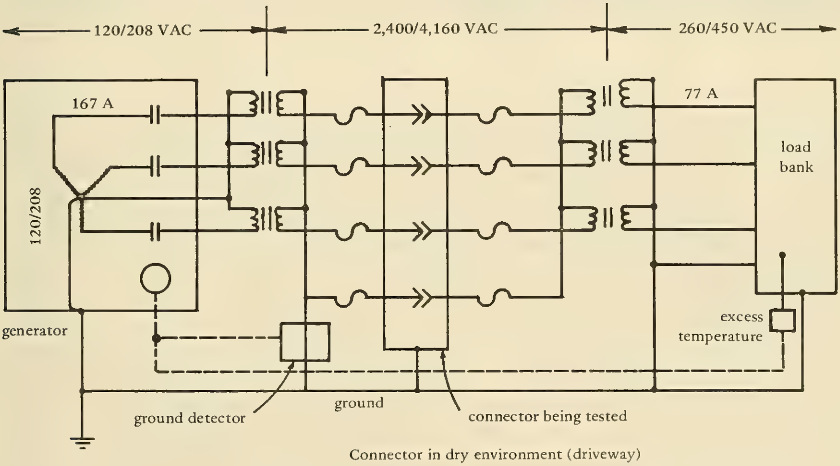
It is important to note that at the conclusion of this test a total of 33 underwater matings had been achieved with no degradation of performance. During these tests pressure-compensating dielectric fluid was not replenished and electrical insulation properties did not change. The dielectric fluid was drained from the connector and found to be free of seawater. A trace of gold particles, from the wiping action of the contacts, was found dispersed in the oil. It is believed that the mechanical wear of the contacts would allow several hundred mating cycles without any maintenance. The pin-wiping O-ring seals were removed and inspected under a microscope for wear or "nibbling" and were found in perfect condition, indicating the reliability of this sealing arrangement.

Remote Mating Test Using Deep Submersibles With Manipulators. Many projected applications of the wet connector depend on the ability to make connections in the deep ocean. To determine the feasibility of this approach the alignment device and wet connector set shown in Figure 21 were fabricated and shipped to New London, Connecticut, for undersea tests utilizing the nuclear research submarine NR-1 and its manipulator. The connectors and test stand were taken to sea by the NR-1 and tested in deep water near the Bahama Islands.

The test was successful. NR-1 unmated and then mated the connector utilizing its manipulator. Difficulties were experienced with the lift lines for the test stand and the currents required reorienting the stand three times during the two hours of testing. Although the connector half could be handled successfully there was need for a more positive grip point for the manipulator claw and for more definite color and pattern keys to display connector alignment and relative motion during mating. These handicaps made the alignment and engaging of the connector halves the most time-consuming portion of

Table 1. Matrix of Required Tests

Parameter	Test Requirement by Technology				
	Insulation	Conductors	Seals	Compensator	Mating Devices
Depth					
Shallow ocean	yes	yes	yes	yes	yes
Deep ocean	yes	yes	yes	yes	yes
Power Level					
Low	yes	yes	NA	NA	NA
High	yes	yes	NA	NA	NA
Mating Method					
Diver	NA	NA	NA	NA	yes
Manipulators	NA	NA	NA	NA	yes
Endurance					
Long	yes	yes	yes	yes	NA
Short	yes	yes	yes	yes	NA



Connector in dry environment (driveway)

Test terminated due to diesel generator problem

Figure 18. Schematic wiring diagram for power transmission tests.

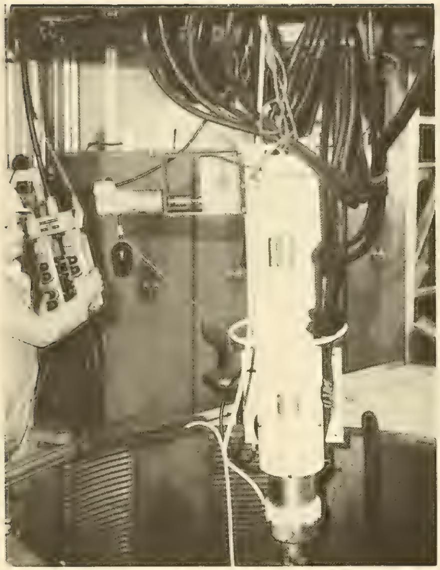


Figure 19. Connector arranged for remote mating and high-power transmission test at high pressure.

the test. It is expected that this problem would be even worse if heavy cables had been attached to the connector halves, so that although this first-ever attempt was successful there is a definite need for further testing of the complete handling and rendezvous problem for complete cable/connector systems. It is interesting to note here that the NR-1 proved an excellent work platform for this operation because of its considerable size, good maneuverability and long bottom-time capability.

SUMMARY

The NCEL connector program began with the SWRI Phase I study to develop a concept for deep-ocean high-power electromechanical connectors in support of the Navy's needs for underwater construction. After a year of extensive sea and laboratory tests the experimental models were only marginally satisfactory and the basic concepts were reviewed. The use of pins and wiping seals was still considered a sound approach but major changes were required in other parts of the hardware design philosophy, including the use of fluid-filled pressure-compensated components, refinements in pin design and improved material selection.

The experimental dry connector was modified to a prototype configuration and used to test the new termination techniques and the pressure compensating system. The wet connectors were also modified to a prototype design to demonstrate the refined pin wiping system and to develop techniques for mating the connectors at sea by divers and by remote actuators or manipulators. General specifications for these prototype connectors, from which detailed designs for specific applications may be derived, are to be included in Reference 7.

The following specific capabilities were demonstrated with the prototype connectors. Note that the test values are not failure points, but rather the limits to which tests were conducted; the prototype equipment has not been tested to failure in any mode.

- Cable termination strength test to 21,000 pounds (design breaking strength is 50,000 pounds, design working load is 14,000 pounds)

- Sustained power at full voltage for 5 months (shallow water)

- Sustained immersion at 6,000 feet in pressure vessel with full power applied for 2 hours on each of three occasions over 5 days

- Thirty-three underwater matings with no degradation (21 at 6,000 feet in pressure vessel, 12 at 4,000 feet in open ocean)

- Operational mating of wet connector by divers at 50 feet in open ocean and transmission of power through the connected system (SEACON I)

- Sustained immersion in open ocean for one year with intermittent power.

Figure 20. Connector and remote mating equipment used during deep ocean test at 4,000 feet.

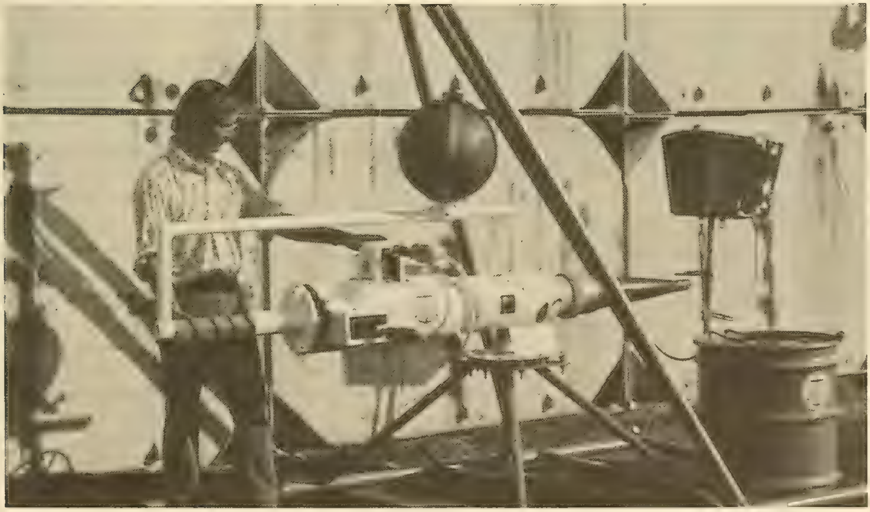


Figure 21. Wet connector with mating system for use in remote mating experiments by submersible manipulators.

CONCLUSIONS

This project has demonstrated that:

1. It is feasible to design, fabricate, and reliably operate deep-ocean cable systems utilizing both wet and dry high-power electromechanical cable connectors.

2. For high-power deep-ocean connectors, a fluid-filled pressure-balanced system is definitely superior to large urethane pots both in operating performance and reparability.

3. The wet mating technique using O-ring seals on pins is effective and is superior to any other existing method for high-power deep-ocean applications.

4. Underwater mating of large electromechanical connectors by divers in the open ocean is feasible.

5. Mating of large connectors by submersible manipulators has been demonstrated. Since deep mating operations are a key link in connector operations, further work is needed in this area.

RECOMMENDATIONS

1. Conduct combined systems tests at depths of 6,000 feet, at 360 kw, incorporating several wet matings at depth over a period of 1 to 5 years. This test should preferably be performed in parallel with some other installed system in order to begin a baseline for operational reliability data.

2. Extend the existing technology to 34.5 kv at several megawatts in preparation for high-power transmission with long undersea cables.

3. Investigate the application of the basic power connector technology to such requirements as high-current umbilical or coaxial connectors.

ACKNOWLEDGMENTS

The authors wish to acknowledge the efforts of Mr. Ed Briggs and the staff of Southwest Research Institute, who designed and built the experimental models. There were also several NCEL personnel who contributed directly to the completion of this development. Mr. R. N. Cordy was the original project engineer and later guided the effort as Director of the Construction Systems Division. LT Robert Bruce, CEC, USNR was assistant engineer during the procurement and early testing of the experimental hardware. Mr. Lee Tucker assisted during the testing of the prototype and Mr. Thorndyke Roe provided supporting expertise in the field of materials compatibility and chemical processes. Especially important throughout were the contributions of Mr. Fred Potter, project technician during the entire program.

REFERENCES

1. Naval Civil Engineering Laboratory. Contract Report CR 68.004: Conceptual study of electrical power transmission systems to deep ocean installations, by I. M. Waitsman. Groton, Conn., General Dynamics Corp., Electric Boat Div., Aug. 1967. (Contract No. N62399-67-C-0015) (AD 662037)

2. F. B. Small and R. T. Weaver. "Underwater disconnectable connectors," in Preprints of the 7th Annual Conference of the Marine Technology Society, Washington, D.C., Aug. 16-18, 1971, pp. 125-134.

3. Naval Civil Engineering Laboratory. Contract Report CR 72.006: A wet and dry deep submergence electrical power transmission system, Phases I and II, by E. M. Briggs, et. al., San Antonio, Tex., Southwest Research Institute, Nov. 1971. 2 vols. (Contract No. N62399-69-C-0001) (v.1 AD 892356L; v.2 AD 892357L)

4. J. F. McCartney and J. V. Wilson. "High power transmission cables and connectors for deep ocean applications," in Preprints of the 8th Annual Conference of the Marine Technology Society, Washington, D.C., Sept. 11-13, 1972.

5. Naval Civil Engineering Laboratory. Technical Report: Seafloor construction experiment, SEACON I, by T. R. Kretschmer, et. al. Port Hueneme, Calif., 1973 (in publication).

6. Naval Ship Research and Development Center. Annapolis Laboratory Report No. 27-8: Handbook of fluid-filled, depth/pressure-compensating systems for deep ocean applications, by T. H. Mehnert. Annapolis, Maryland, April 1972.

7. General Dynamics Corp., Electric Boat Div. Report No. U-413-68-030: Handbook of vehicle electrical penetrators, connectors and harnesses for deep ocean applications, by R. F. Haworth, et. al. Groton, Conn., July 1971. (Contract No. N00024-68-C-5434)

8. Naval Civil Engineering Laboratory. Final Report: Feasibility study of scaling up the low voltage underwater disconnectable connector for high voltage applications, by W. Michelson, et. al. Syracuse, N.Y., Crouse-Hinds, July 1972. (Contract No. N62399-72-C-0016)

Appendix

ALTERNATE WET CONNECTOR CONCEPTS

In preparation for the prototype wet connector design another review was made of the existing connector techniques. A summary of the various methods for making electrical contact underwater follows:

Method	Manufacturers/Developers
Pin types (utilizing wiping seals)	Naval Civil Engineering Laboratory (NCEL) Mare Island Naval Shipyard (MINSY) Commercial
Diaphragm puncture	Commercial
Grease displacement	Commercial
Split transformer	Commercial
Compression wiping (button contacts)	None

Figure A-1 shows the general appearance and relative size of these other wet connectors.

The Mare Island Naval Shipyard connector [2] is a 440-volt power connector with a successful experimental model already in existence. It was designed specifically for use by divers with submarines and is small and light to handle. It would require fabrication of a mating guide mechanism to be compatible with a manipulator. It is somewhat complex, and is not designed for heavy mechanical loads.

Most commercial pin-wiping power connectors are quite small and inexpensive but operate at power levels far below those required for major structural applications. They require considerable force to mate and are not now adapted for use by manipulators. The materials used are not suitable for direct application to high voltage and degrade unacceptably with extended submergence.

The commercial diaphragm-puncture connector operates at up to 600 volts, has eight contacts, and is very simple. It is between the NCEL and MINSY connectors in size and capacity and is the only right-angle power connector found. It is mated by set-screws. This connector combines many of the features required for structural applications but has not been tested for higher voltages or deep submergence.

One company uses a grease-filled connector for automatic connection of submersible pumps. The connector configuration is different from most in that the contacts are in line rather than in parallel, so that the connectors are insensitive to rotational alignment. The contacts are simply concentric rings spaced along the male pin and female cylinder respectively. This offers a much easier mating arrangement, especially for remote operations. Unfortunately the concept is still experimental and has not been adapted for use in the ocean environment. The exposed grease surface is particularly vulnerable to contamination.

Split-transformer and related electromagnetic coupling techniques are normally not applicable to high power connectors because of the large size and weight of transformers of kilowatt capacity. There are several commercial products which use this concept for coaxial and other signal applications, however, and the extreme simplicity and reliability of the mating operation make this method very attractive for further development.

Analysis of these designs and the experience gained from each of them indicated that the pin-types were best suited to high-voltage, deep-submergence use. The success of the mechanical portions of the Mare Island Naval Shipyard design indicated that their experience would be of value in the development program, so a small contract was awarded to determine the feasibility of scaling up the 440-volt design to the NCEL high-power

electromechanical applications [8]. The study concluded that their mechanism could be adapted to the NCEL requirements, but the time and cost of that approach were greater than the program could support. The decision was made to modify the existing NCEL experimental hardware to approximate the prototype design as closely as possible and to thoroughly exhaust the possibilities of the basic NCEL design before moving to other concepts (if necessary).

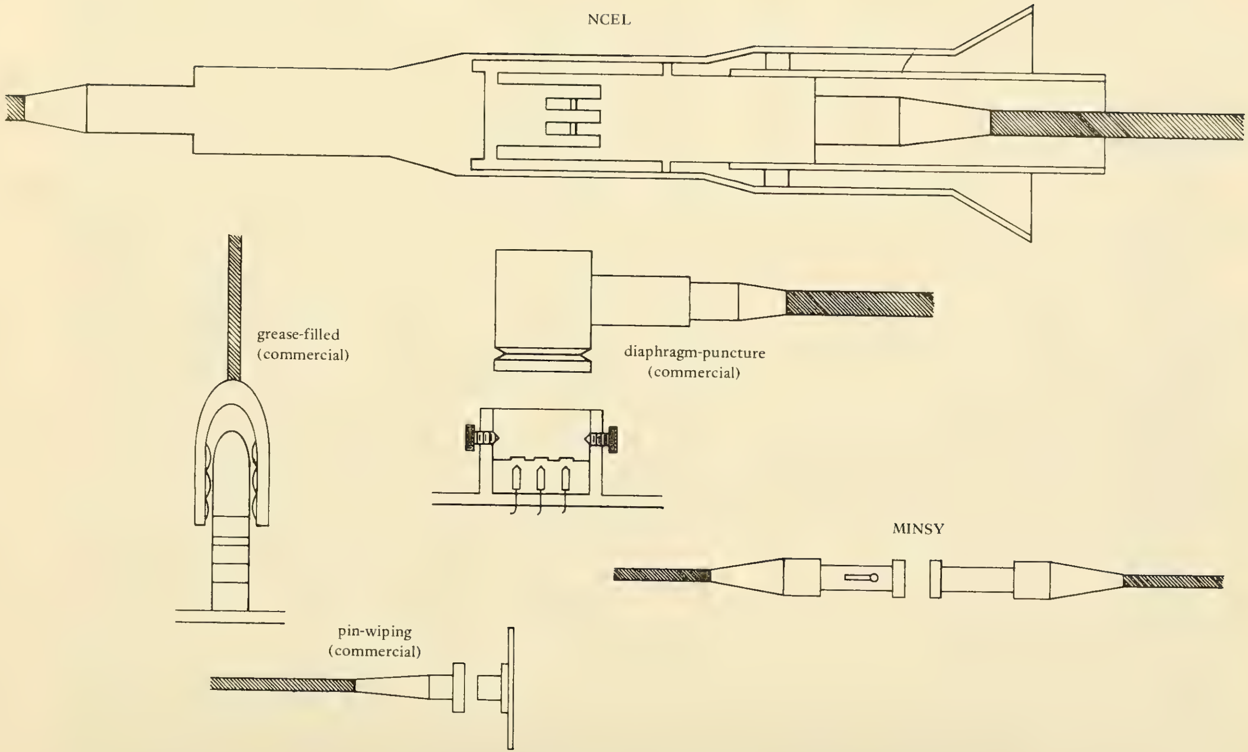


Figure A-1. Other wet connectors.

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TR-806 31 p. illus Apr 1974 Unclassified

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